Effects of the Development of the Baikal-Amur Mainline Railroad on Patterns of Boreal Forest Cover and Carbon Fluxes in Southern Siberia

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Part I.
Perspectives on Land Cover Change in the Boreal Forest Region

Issues in Conducting Global Change Research in the Boreal Forest Region - Dealing with Scientific Perspectives

The Scientific Process has 3 important steps

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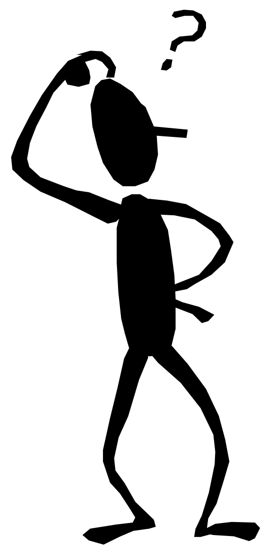


Examine the Data | **Ponder the Facts** | **Form Conclusions**

Issues in Conducting Global Change Research in the Boreal Forest Region - Dealing with Scientific Perspectives

- **Problems**
  - **In the terrestrial science community, global change science is often not conducted by researchers who are trained using a global perspective, but by researchers with unique biome or geographic perspectives**
  - **Conclusions are often drawn about specific processes in a biome/region based upon perspectives developed in other biomes/regions**
- **Examples**
  - **Fire in the boreal forest is not an important process on a global scale**
  - **Just as in the temperate forest, tropical forest and savanna regions, human activities are a primary driver behind land cover change**

Relative Importance of Fires in the Boreal Forest
(as viewed by the "global" fire community)

Biome	Carbon Released (Tg/yr)	Percent of Total
Savanna	1660	70
Tropical Forests	570	24
Temperate Forests	107	5
Boreal Forests	23	1

Seiler and Crutzen 1980; Hao, Liu and Crutzen 1990

Estimated Annual Rates of Disturbance in the Boreal Forest(millions of hectares)

Source of Disturbance	Area (average)	Percent (average)
Total	6 to 24 (15)	
Human land clearing	2 (2)	33 to 8 (13)
Insects/pathogens	2 to 4 (3)	33 to 17 (20)
Fire	2 to 18 (10)	33 to 75 (67)

Data Availability for Studies of Land Cover Change in the Boreal Forest Region

Over the past decade, the satellite remote sensing community has created a nur of important initiatives to collect the data sets necessary to document patterns disturbance and land-cover change in many regions of the earth

Biome/Region	*Disturbance/Land Cover Change Pattern*	*Data Set Initiative*
Temperate Forests/U.S.	**Patterns of forest clearing and regrowth**	**NALC, MLRC**
Tropical Forests/S. America, SE Asia	**Deforestation**	**AVHRR/Landsat Pathfinders**
Savannas, Tropical Forests/SE Asia, Africa, S. America	**Seasonal fires**	**Global AVHRR/ATSR Fire Maps**
Boreal Forest/Russia, N. America	**Summer fires, insects, deforestation**	**???????**

Key Unresolved Questions with Respect to Land Cover Changes in the Boreal Forest Region

- What is the annual area burned and area disturbed by insects and diseases?
- Are fires in the Russian boreal forest predominately surface fires (as maintained by Russian forestry community) or crown fires (as suggested by satellite observations)?
- What are the levels of greenhouse gases released directly from fires and during the years immediately after fire (due to post-fire soil respiration enhancement)?
- In the southern and far-eastern portion of the Russian boreal forests, what are the rates of forest clearing due to human activities?

Key Unresolved Questions with Respect to Land Cover Changes in the Boreal Forest Region

- In response to recent distinct trends in warming in the boreal region:
- Are levels of fire increasing in the boreal region (in terms of area burned as well as fire severity)?
- Are levels of insect and disease infestation increasing?
- At what rate are the northern boundaries of the boreal forest expanding?
- Are patterns of forest recovery after disturbance changing (indicated by a shift from coniferous forests to deciduous forests)?
- Is the ratio between forest area and non-forest area (peatlands) in the boreal region increasing or decreasing?
- Will the boreal forest region remain an atmospheric carbon sink or will it become an atmospheric carbon source?

Episodic Fire Years in the Boreal Forest

Region	*Year*	*% of Total Area Burned*
Khabarovsk/Sakhalin Island	**98**	**5.0**
Boreal Plains	**80-81**	**4.2**
Alaska Boreal	**90-91**	**4.2**
West Taiga Shield	**94**	**4.8**
West Boreal Shield	**80-81**	**4.4**
East Taiga Shield	**90**	**3.0**

The Role of Land Cover Change in the Boreal Forest Region

- **On a relative scale, direct human activities are responsible for a small portion of land cover change in the boreal region**

- **Natural disturbances (fire, insects, disease) play a far greater role in land cover change than do human disturbances**

The Role of Land Cover Change in the Boreal Forest Region

- **The increase in large-scale, natural disturbances associated with climate change will have significant socio-economic impacts on human society**
- **Increased fire activity represents a significant and direct threat to human life and property**
- **Any human-related activity that occurs in the boreal region has to consider fire, especially those associated with exploitation of natural resources**
- **Increased fire and insect/diseases will reduce the amount of wood and fiber available for harvesting**
- **Increased fire will change the habitat for a wide range of fish, bird and wildlife species, many of which are commercially exploited or used by indigenous peoples**
- **Increased fire will alter the availability of other products harvested from forested landscapes (mushrooms, berries, etc.)**

The Role of Land Cover Change in the Boreal Forest Region

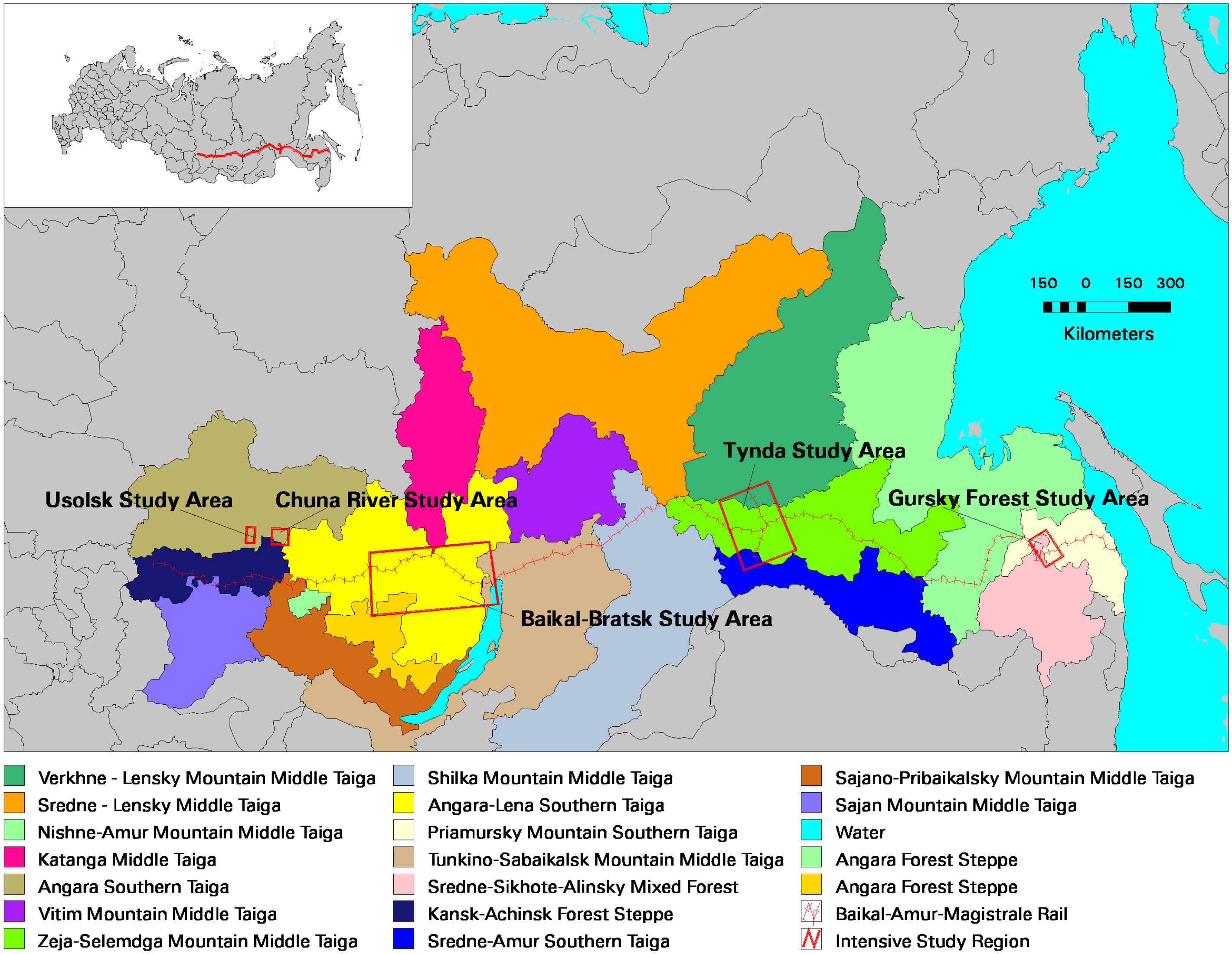
- Alteration of the fire regime will have significant impacts on global climate change treaties
- Issue of carbon credits in the Kyoto Protocol
- Increased fire will influence the debate on allocation of funding for natural resource management
- Command and Control Viewpoint
  - Given sufficient resources (manpower and equipment), all fire can be controlled
- Ecological viewpoint
  - Even with unlimited resources, natural fire cannot be controlled or even reduced. Efforts should be focused on protecting high-priority life and property

Values at Risk in the Boreal Forest

- While the boreal forest region has a low population density, it is home to a large population of Native Peoples who maintain traditional, subsistence-based lifestyles
- The southern boreal forest contains significant timber resources that may be exploited in the future
- The boreal forest region contains the largest terrestrial carbon reservoir
- Significant non-renewable resources exist in this region, and the routes for NRR in the Arctic go through the boreal forest
- The boreal forest region provides habitat for a large number of fish, bird and mammal species

Part 2:
Monitoring Land Cover Changes in the BAM Regions - Examples and Challenges

BAM Intensive Study Sites



Summary of Project Goals, Objectives, and Deliverables

- **Goal: Develop a better understanding of the role of human disturbance on patterns of carbon storage and assessment along the Baikal-Amur Mainline (BAM) Railroad**

- **Objectives:**
  - **Create a baseline map of forest fire locations for the BAM for the period of 1980 through 1990 and later periods where possible**
  - **Use the fire maps to estimate the amounts of carbon lost from fire along the BAM**
  - **Using available Landsat imagery, create maps of human-caused deforestation and patterns of reforestation along the entire length of the BAM**
  - **Develop models of forest regrowth for the different forest ecoregions along the BAM**
  - **Combine the forest regrowth models with information on patterns of forest disturbance and regrowth derived from satellite imagery to estimate carbon forest fluxes along the BAM**

Mid-Course Corrections

- An analysis of the Landsat archive revealed there is not enough imagery available to achieve Objective 3 of the study
- Over the past year, we have developed approaches to merge use higher resolution (5 to 80 m) satellite imagery from multiple sources to monitor and map forest clearing and regrowth at our test sites
- Based on these analyses, we have decided to limit our studies to four specific test sites that have varying degrees of human and natural disturbance:
  - Chuna Test Site - high rates of human land clearing over a very long time period (1960 to present)
  - Usolsk Test Site - more recent (after 1980) human land clearing combined with heavy disturbance from insects and moderate fire disturbance
  - Tynda Test Site - Human land clearing since the 1980's combined with moderate natural fire
  - Gursky Test Site - Heavy disturbance from fire, especially in 1998

Common Interest with other LCLUC Projects

- **We have established links with several other LCLUC projects**
  - **We will work with the McGuire Project to estimate carbon emissions from fire for the entire boreal forest**
  - **Will will work with the DeFries Project to evaluate the ability of the continuous forest cover product to detect deforestation in boreal forests**

Key Components of BAM Study

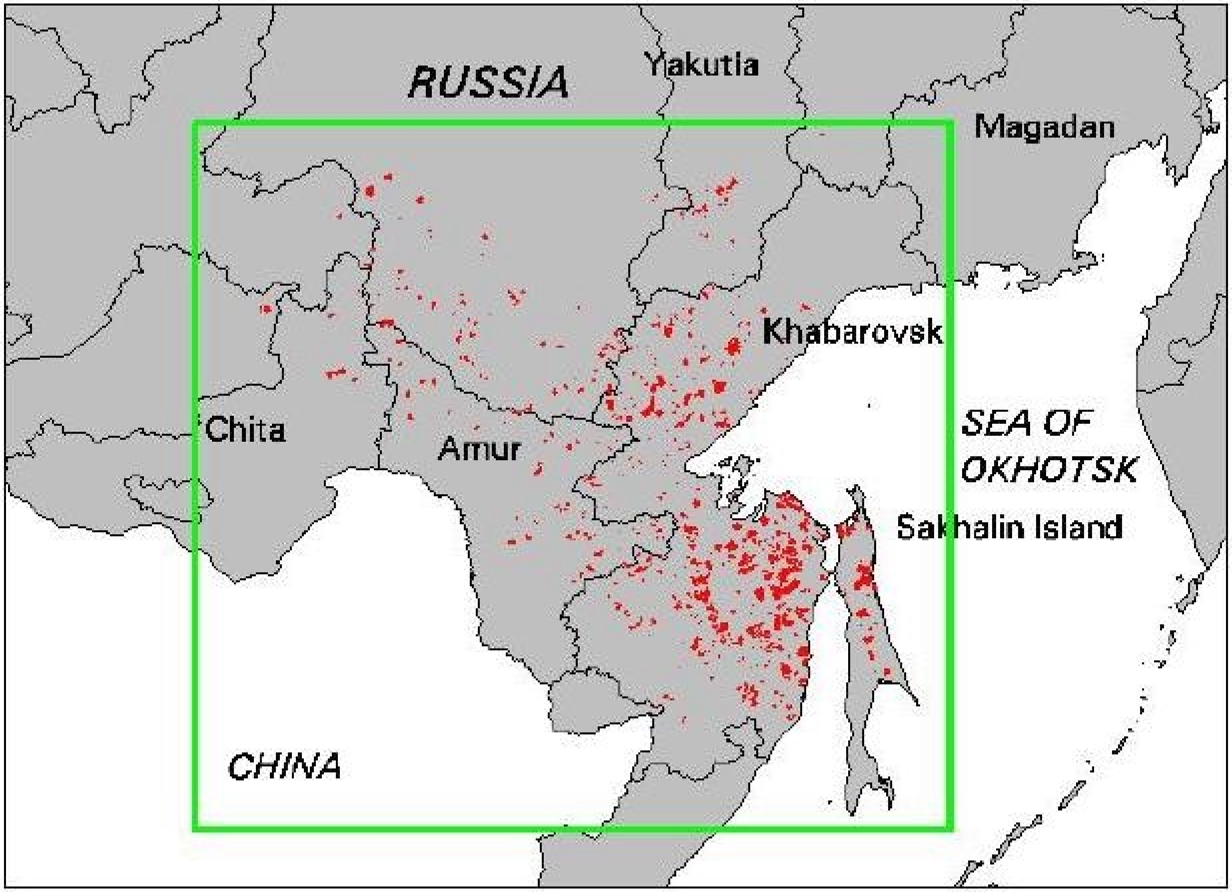
- **Patterns of Fire Disturbance Using AVHRR Imagery**
- **Sub-regional scale patterns of deforestation/reforestation using multiple-resolution satellite imagery**
- **Modeling patterns of forest regrowth/carbon sequestration**

Patterns of Fire Disturbance Using AVHRR Imagery

Patterns of Fire Disturbance Using AVHRR Imagery

- **Use AVHRR to document location and extent of fires in the Russian boreal forest during the 1980's and early 1990's**
- **Study spatial/temporal patterns of fire**
  - Relative to the BAM
  - Relative to other boreal regions (North America)
- **Estimate greenhouse gas emissions from Russian fires**
  - Compare to North American estimates

Significant Event in the Study Area: 1998 Severe Fires in Eastern Siberia Mapped from AVHRR



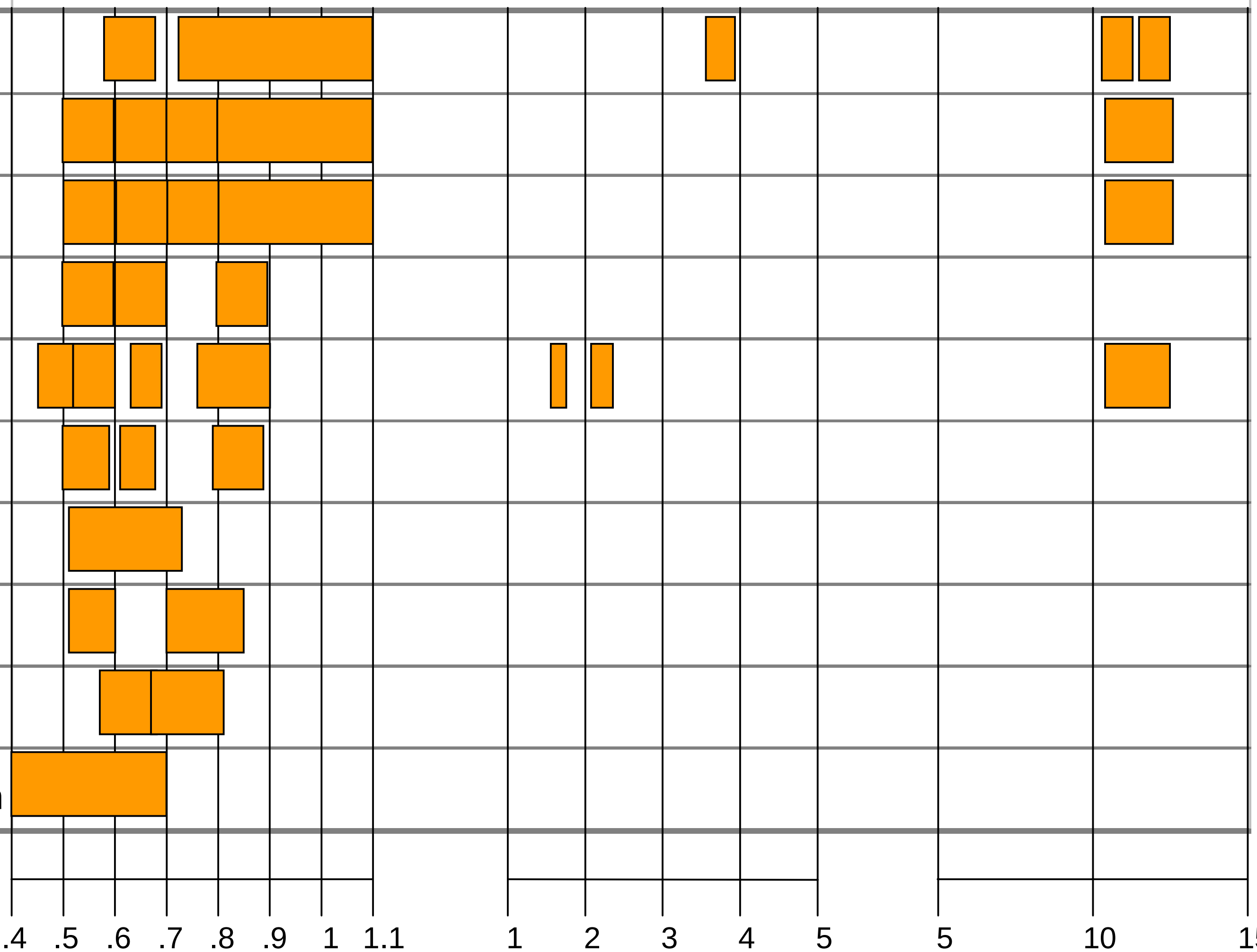
Sub-regional scale patterns of deforestation/reforestation using multiple-resolution satellite imagery

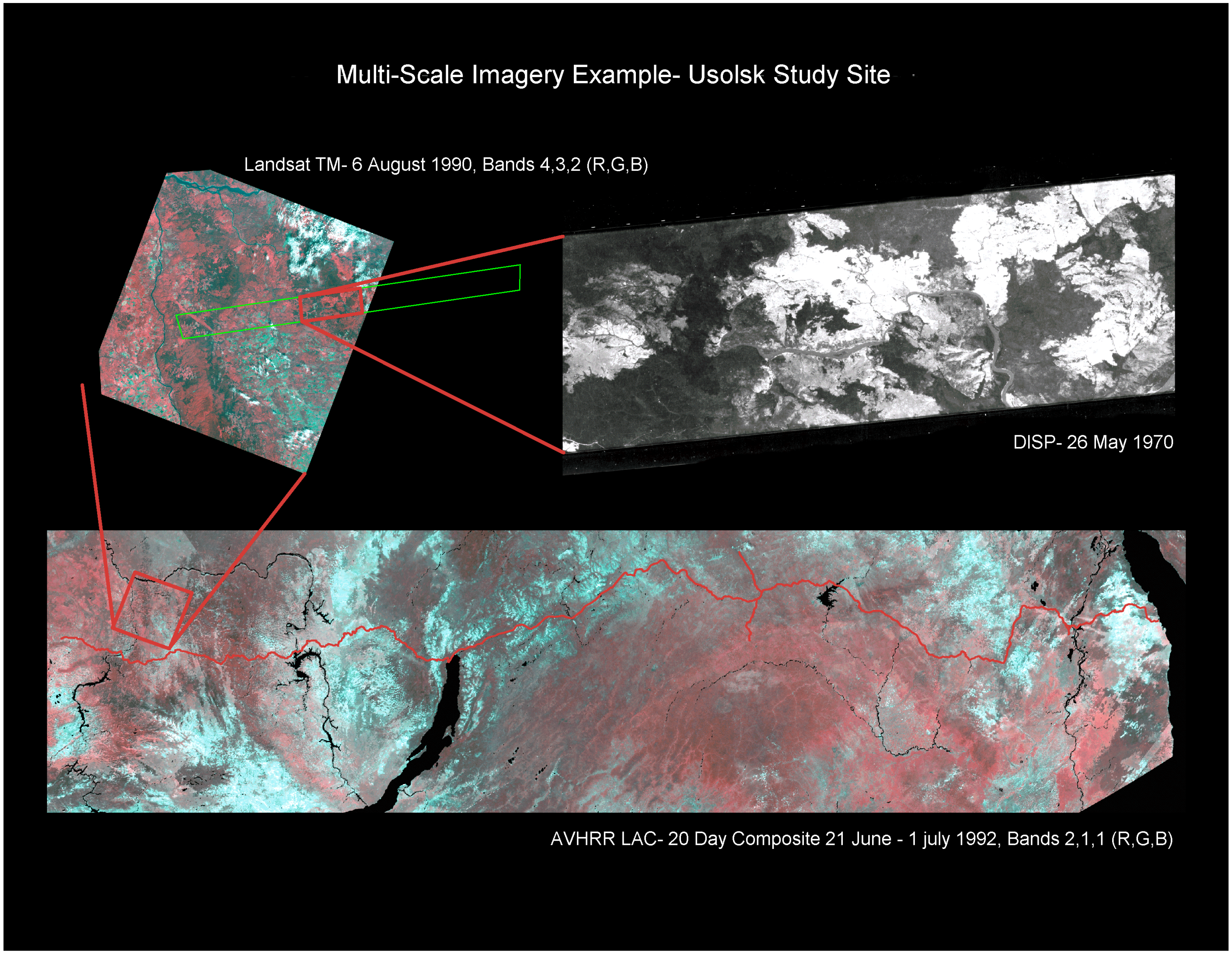
Sub-regional Scale Patterns of Deforestation/Reforestation Using Multiple-Resolution Satellite Imagery

- **Focus on three regions of Russia where anthropogenic deforestation is occurring**
    - Biryusa River Basin (two sites)
    - Tynda Region
    - Gursky Forest Region
- **Address issues related to using satellite imagery to monitor changes in forest cover in these regions**
- **Detection of disturbance as a function of system resolution**
- **Analysis of deforestation using multiple-satellite systems**
- **Analysis of reforestation using time-series MSS data**
- **Comparison to theoretical forest growth models - model validation**

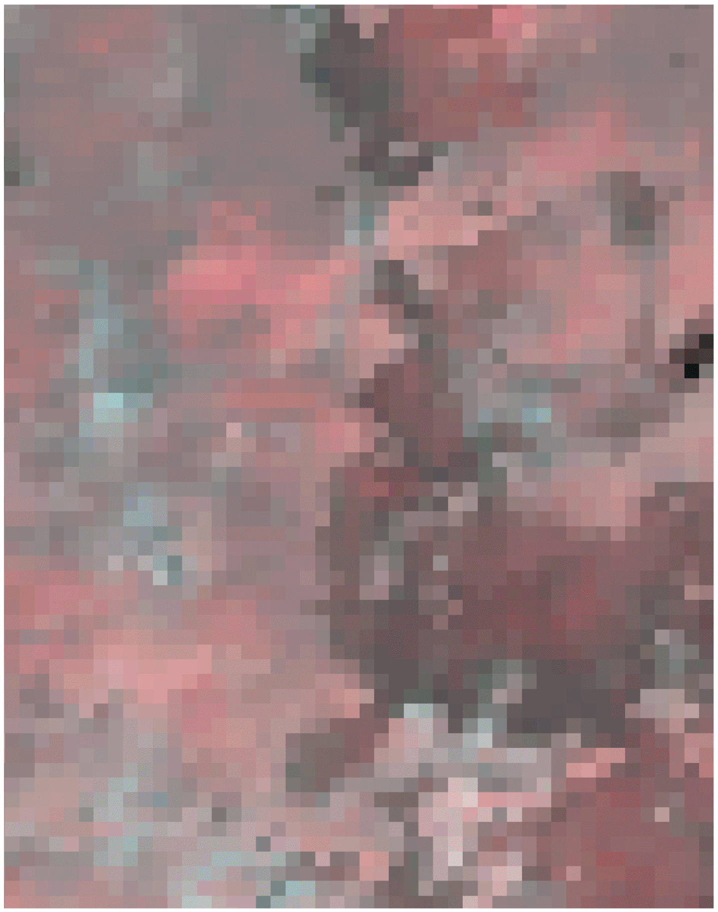
Sensor Characteristics

Sensor	Resolution	Extent	Spectral Range
AVHRR	1.1 km	2580 km	
MSU-SK	170 m	250km	
MSS	80 m	185 km	
MSU-E	45m x 33 m	45 x 220 km	
TM	30 m	185 km	
SPOT-XS	20 m	60 km	
SPOT-PAN	10 m	60 km	
MK-4	~6 m	120 km	
KFA-1000	5 m	60 km	
DISP	~6 m	~15 x 209 km	

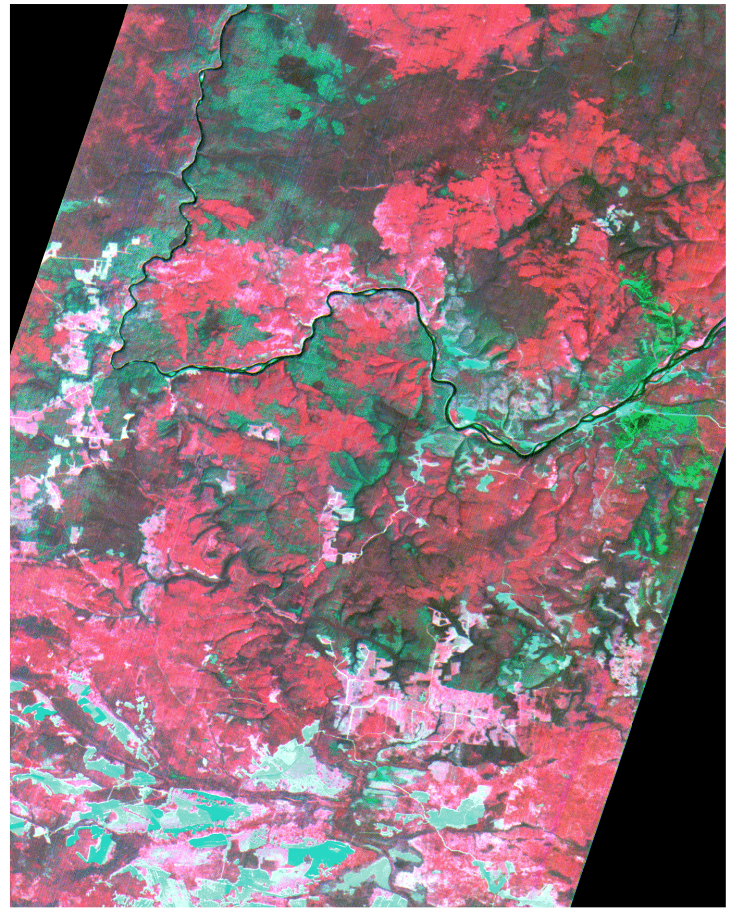



Multi-Scale Imagery Example- Usolsk Study Site
Landsat TM- 6 August 1990, Bands 4,3,2 (R,G,B)
DISP- 26 May 1970
AVHRR LAC- 20 Day Composite 21 June - 1 july 1992, Bands 2,1,1 (R,G,B)

Usolsk Study Area- Image Resolution Comparison



1 km Cell Size
AVHRR 20 Day Composite-
21 June 1992 - 10 July 1992, Bands 2,1,1 (R,G,B)



35 M Cell Size
MSU-E- 28 June 1997, Bands 3,2,1 (R,G,B)

Chuna River Forest Change Study

ISSUES UNDER INVESTIGATION

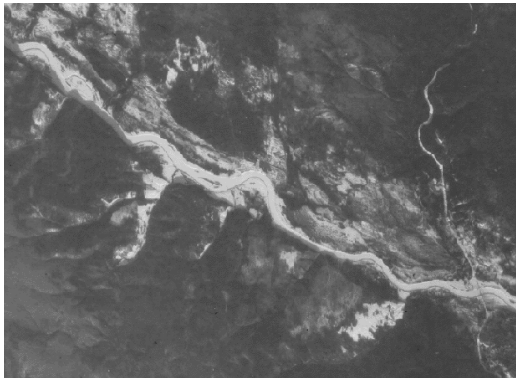
- Extraction of useful information
  - Forest cutting
  - Forest regeneration

- Extraction of comparable information from different types of remote sensing data (for example, DISP, Landsat, KFA-1000)

- Assessment of data adequacy
  - Geographic coverage
  - Temporal frequency
  - Phenological equvalence
  - Phenomenologic suitability

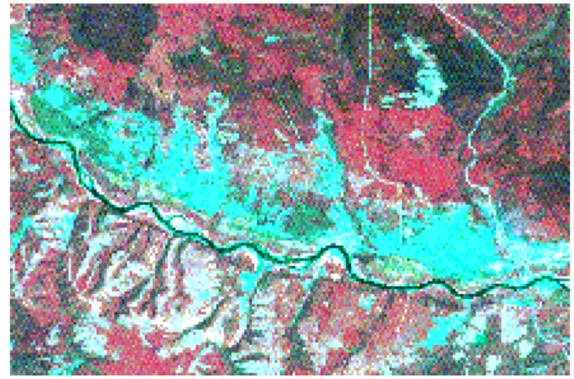
Time Series/Sensors for Chuna Site

Four decades by combining U.S. and Russian Sources

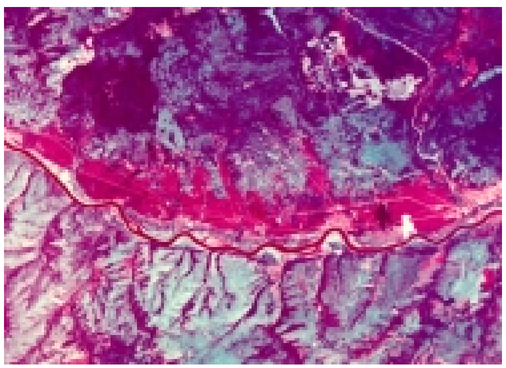


DISP
1965

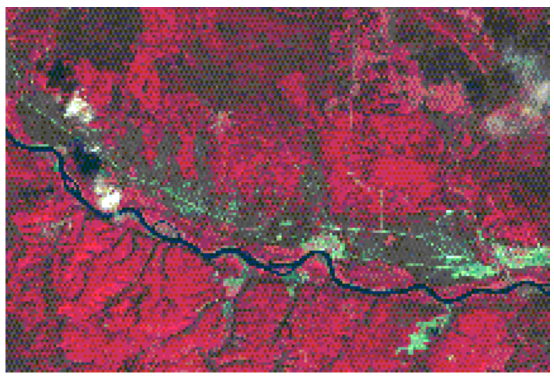
DISP
1970



LANDSAT MSS
1974



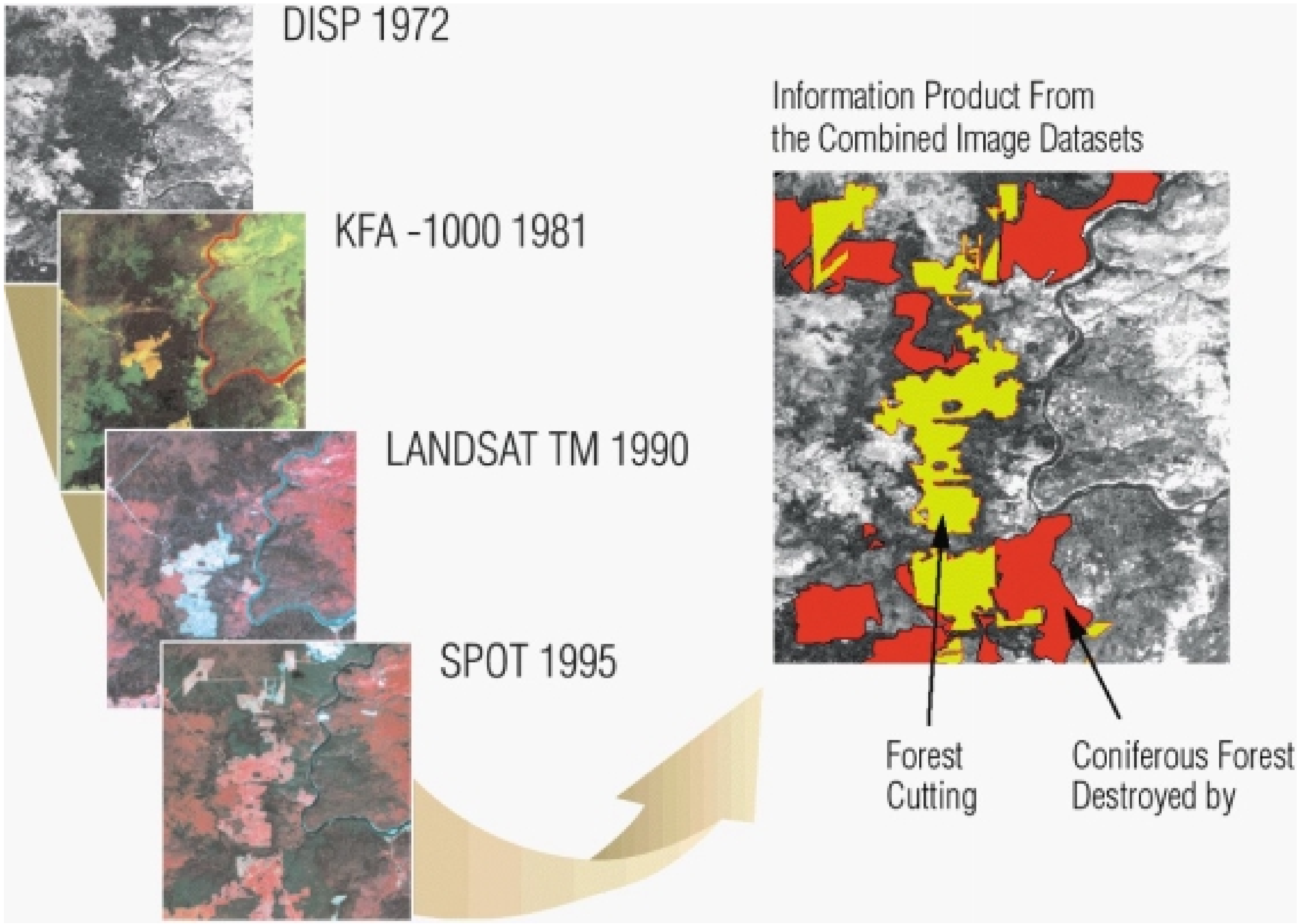
KFA-1000
1983



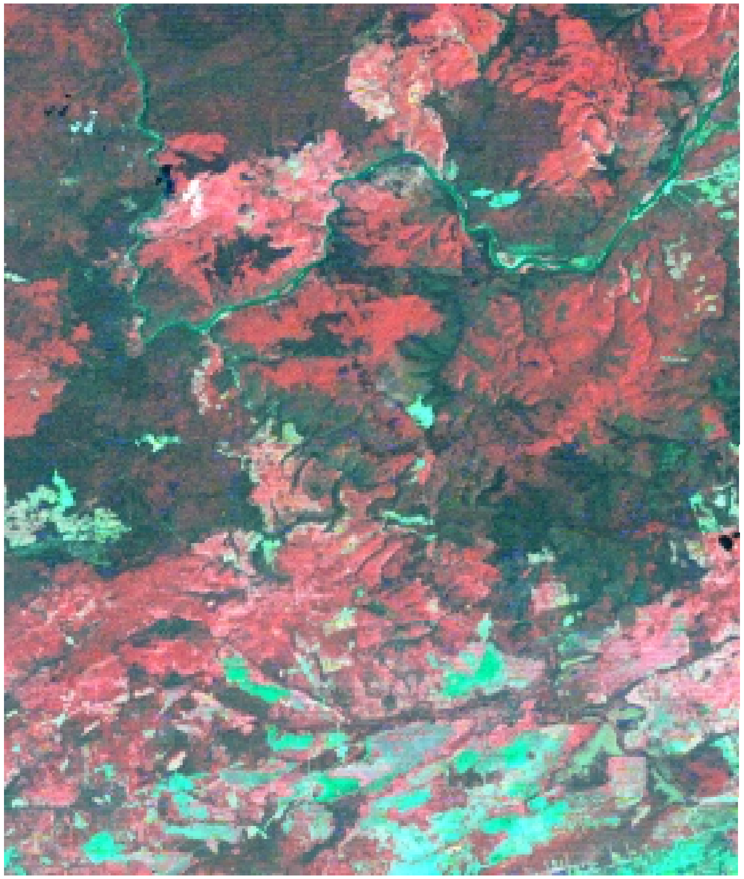
LANDSAT TM
1990

Congratulations on a Successful LANDSAT 7 Launch!

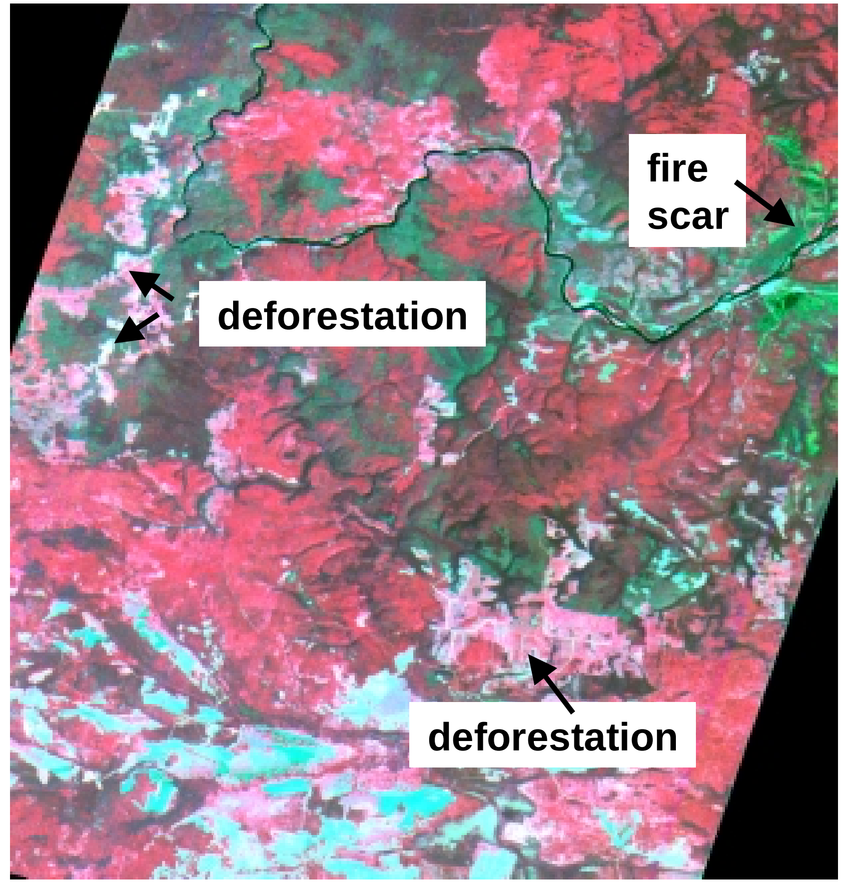
LANDSAT TM
1999


DISP 1972
KFA -1000 1981
LANDSAT TM 1990
SPOT 1995
Information Product From
the Combined Image Datasets
Forest
Cutting
Coniferous Forest
Destroyed by

Additional Site Example: Krasnoyarsk--Usolsk



1980 U.S. Landsat MSS



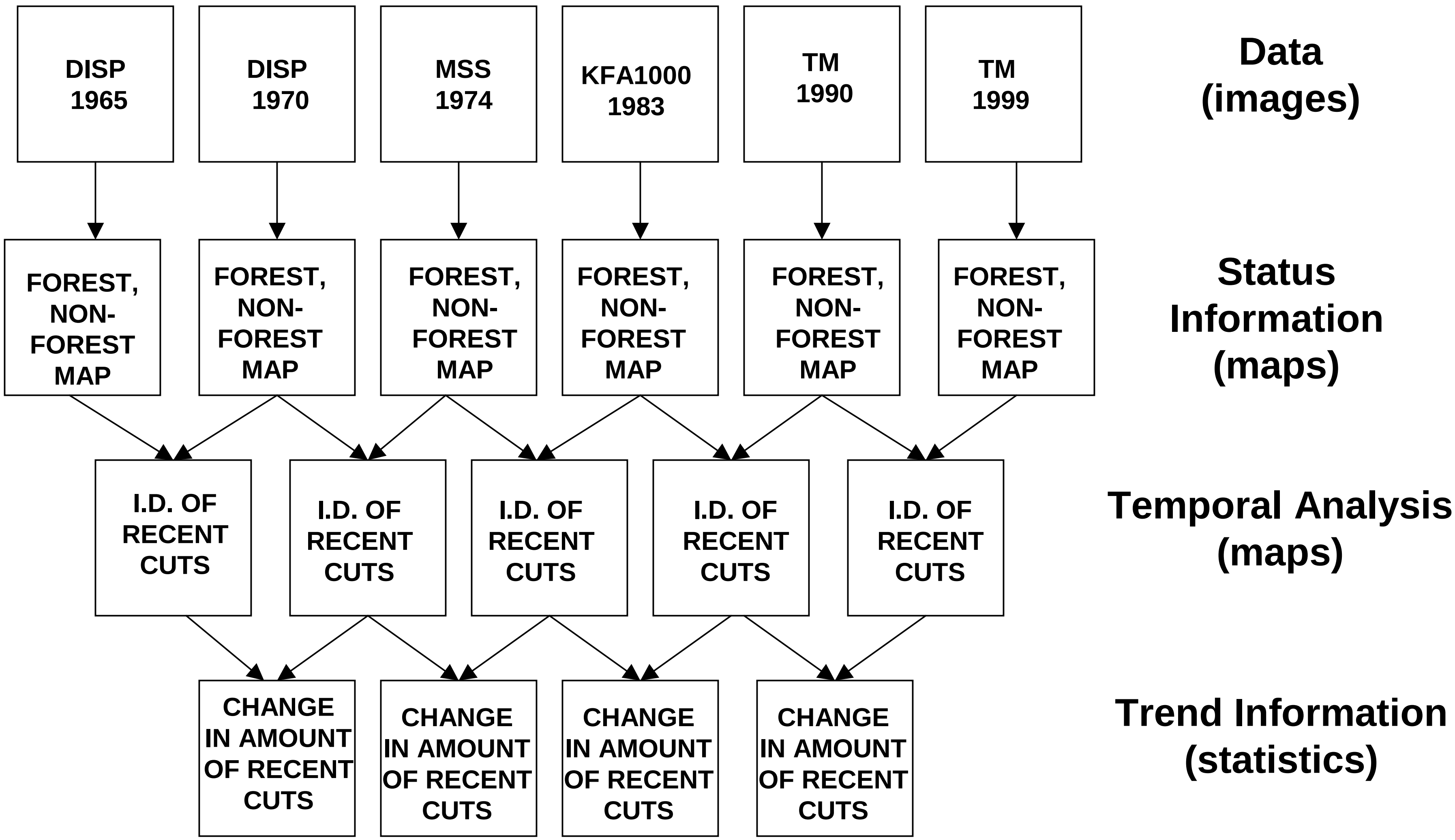
1997 Russian MSU-E

0 10 km

Overview of Forest Harvesting Procedure

- **Forest harvesting is characterized by removal of tree cover.**
- **Removal of tree cover produces a distinct change in the spectral properties of an area.**
- **For each acquisition of remote sensing data, the study area is categorized into forest and non-forest.**
- **Areas that change from forest to non-forest are considered to have been cut during the time interval between acquisitions.**
- **Annualized cutting is calculated by dividing the area cut within a time interval by the number of years in the interval.**
- **Trend information is derived from the change in the amount of area cut per time interval.**
- **Sustainability of forest cutting is estimated by comparing the average annual cut with the nominal rotation cycle of the forest type being cut.**

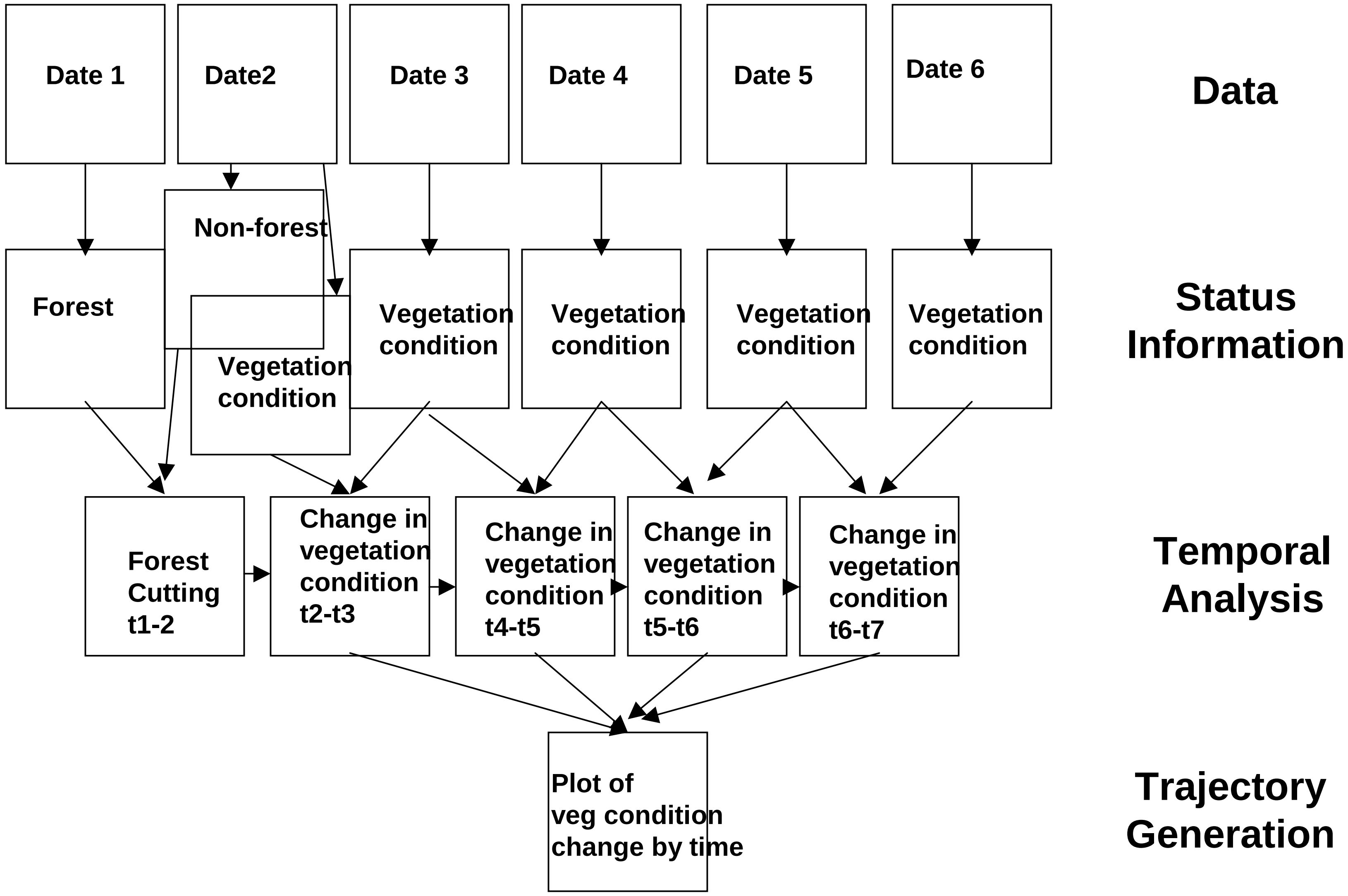
Forest Harvesting



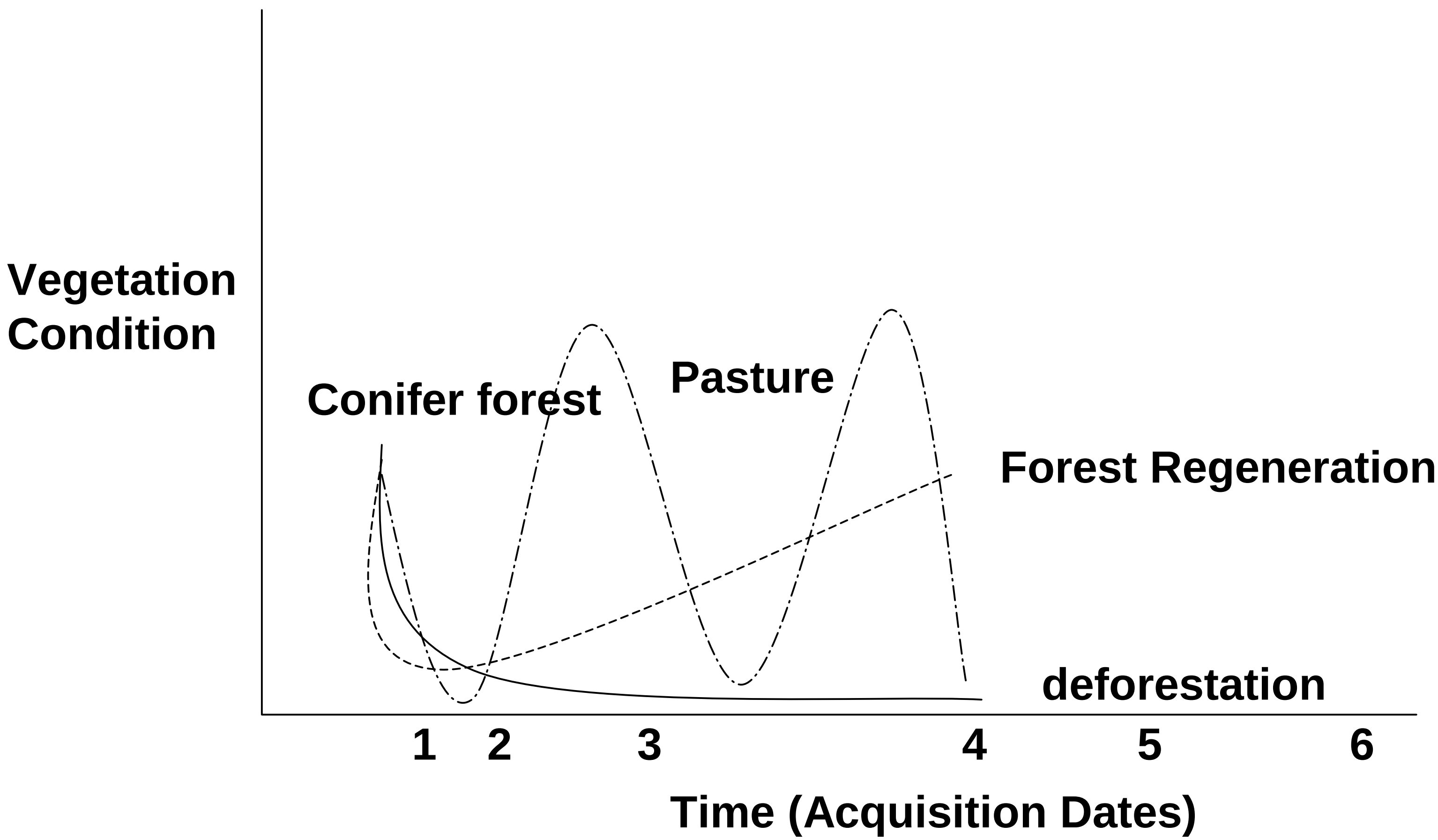
OVERVIEW OF FOREST REGENERATION ASSESSMENT PROCEDURE

- Forest regeneration assessments will be made on areas where removal of forest cover is detected, based on acquisitions after the removal of forest.
- Removal of forest cover is detected by comparing land cover categories between pairs of images.
- Regeneration assessment is based in part on the condition, and changes in condition of the vegetation cover that is present in the time intervals following forest clearing.
- The length of the regeneration period available for analysis depends on in which time interval forest cutting was detected.
- For areas where regeneration has had many years to develop, it may be possible to assess the relative amount of hardwoods versus conifers present.

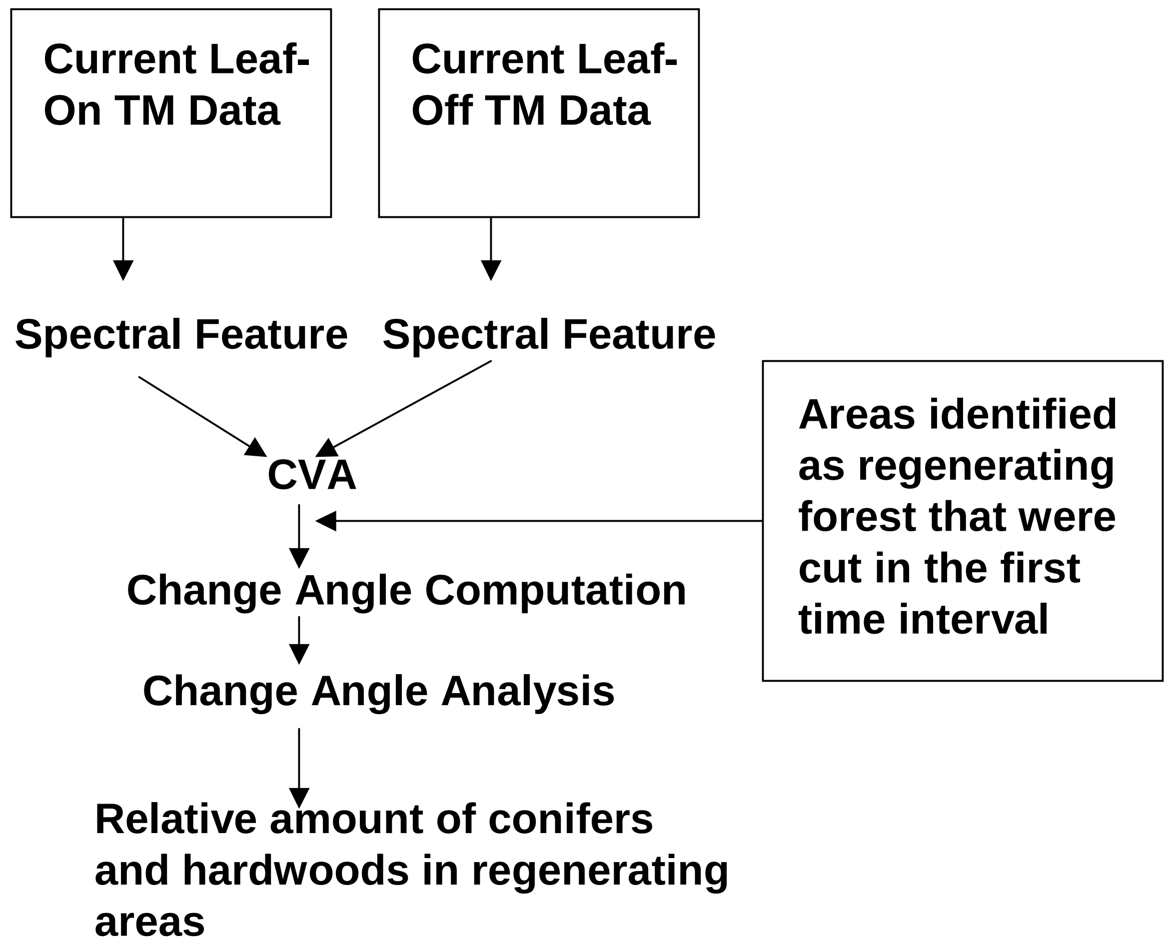
FOREST REGENERATION ASSESSMENT FOR FIRST TIME INTERVAL



VEGETATION CONDITION TRAJECTORY ANALYSIS FOR AREAS CUT IN FIRST TIME INTERVAL



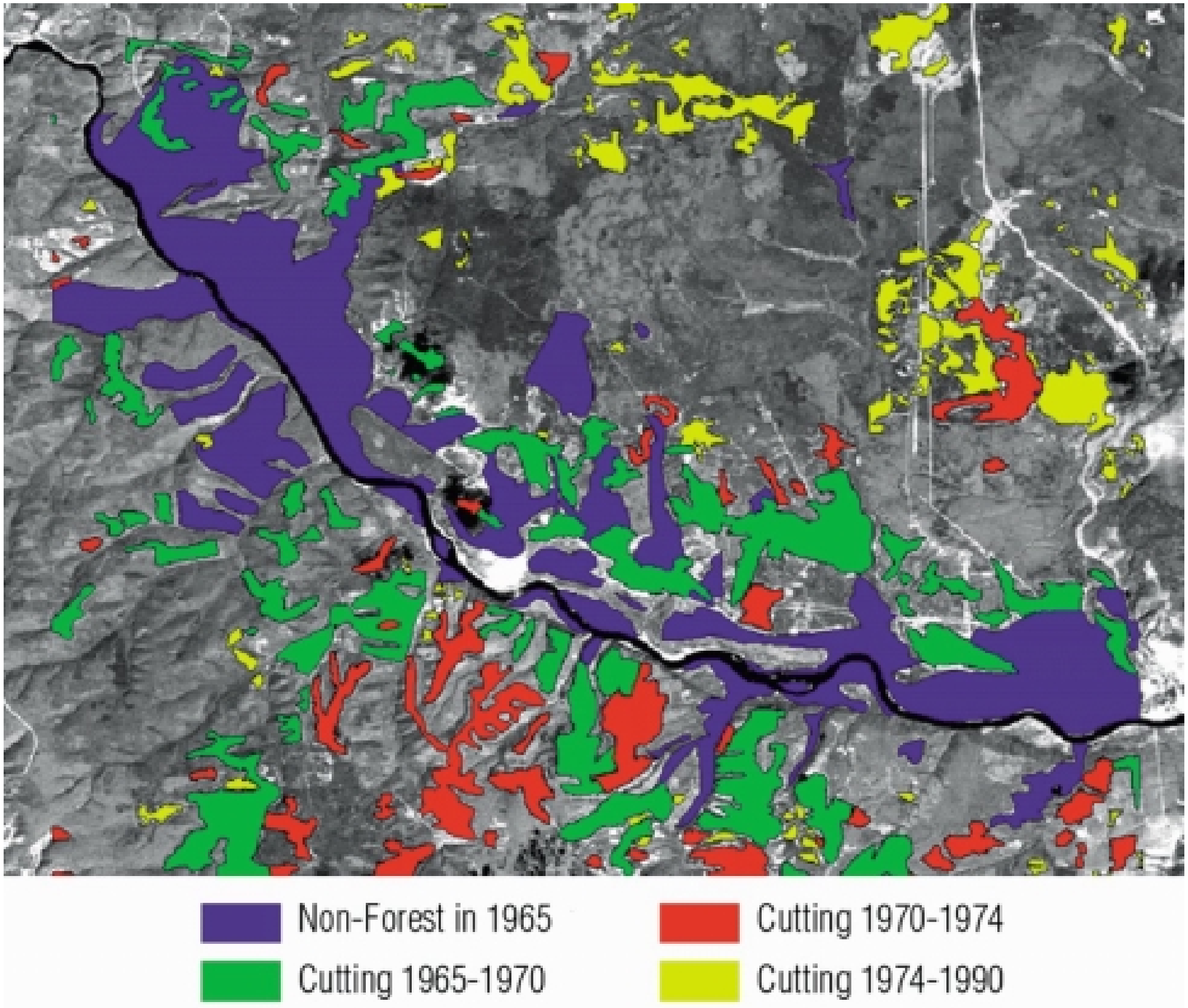
FOREST REGENERATION COMPOSITION ASSESSMENT FOR AREAS CUT IN FIRST TIME INTERVAL



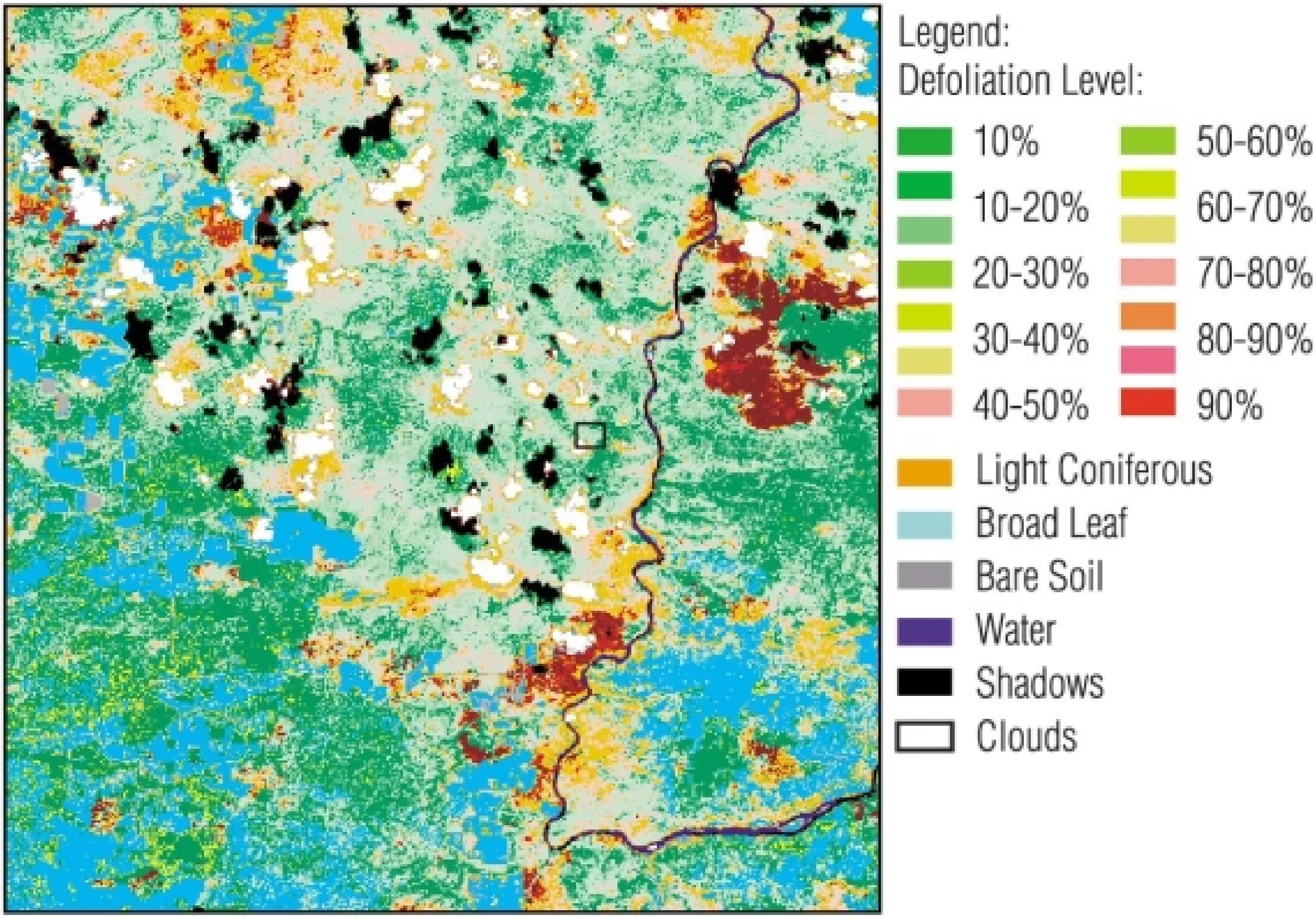
Chuna River: Preliminary Results

- **Equivalent information about forest harvesting can be extracted from a variety of combinations of historical remote sensing data. This capability makes it possible to assemble a set of acquisitions with sufficient temporal frequency to effectively monitor forest cutting.**
- **Phenological timing of some of the acquisitions may make regeneration assessment more difficult.**
- **Large area coverage sensors (like Landsat) may help assess the representativeness of information derived from higher spatial resolution sensors (like DISP).**
- **Data adequacy is likely to vary on a case-by-case basis. DISP data may limit geographic coverage. Differences in phenology between acquisitions may make interpretation difficult.**
- **Ortho-rectification of the DISP and KFA data is difficult, but should greatly facilitate comparisons between acquisitions.**

Deforested Areas near the Chuna River 1965-1990 Generated Through Analysis of DISP and Landsat



Map of Defoliation in the Biryusa River Basin from Siberian Silkworm Outbreaks 1994-1996 using SPOT Imagery



Map of Forest Defoliation Created by SPOT Imagery

Part III.
Modeling Patterns of Forest Regrowth/Carbon Sequestration

Modeling Boreal Forest Succession and Disturbance in the Krasnojarsk Kray Forest of Siberia

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Objectives:

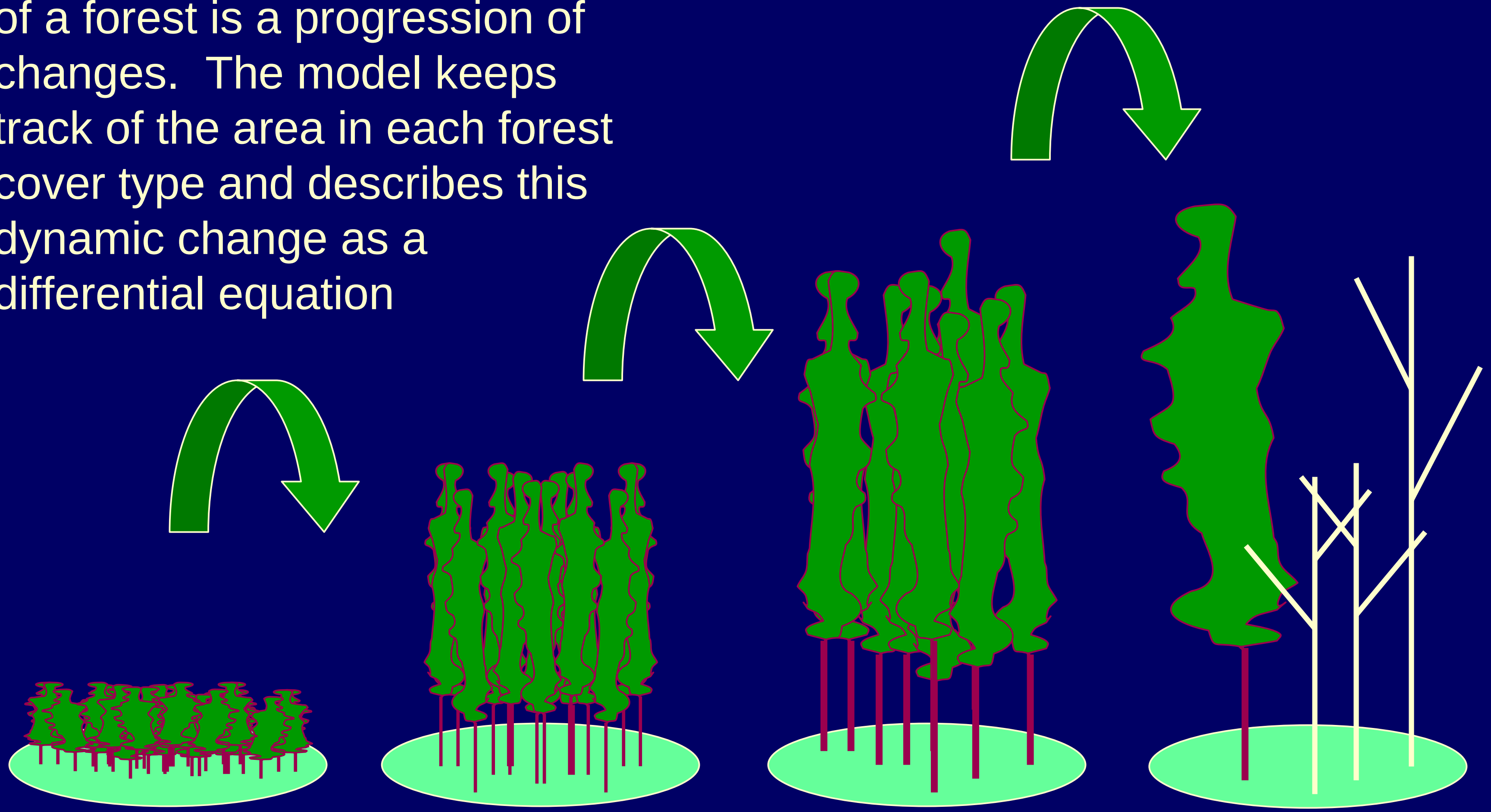
- To create a landscape scale succession model of Krasnojarsk, Siberia that incorporates fire and insect infestation.

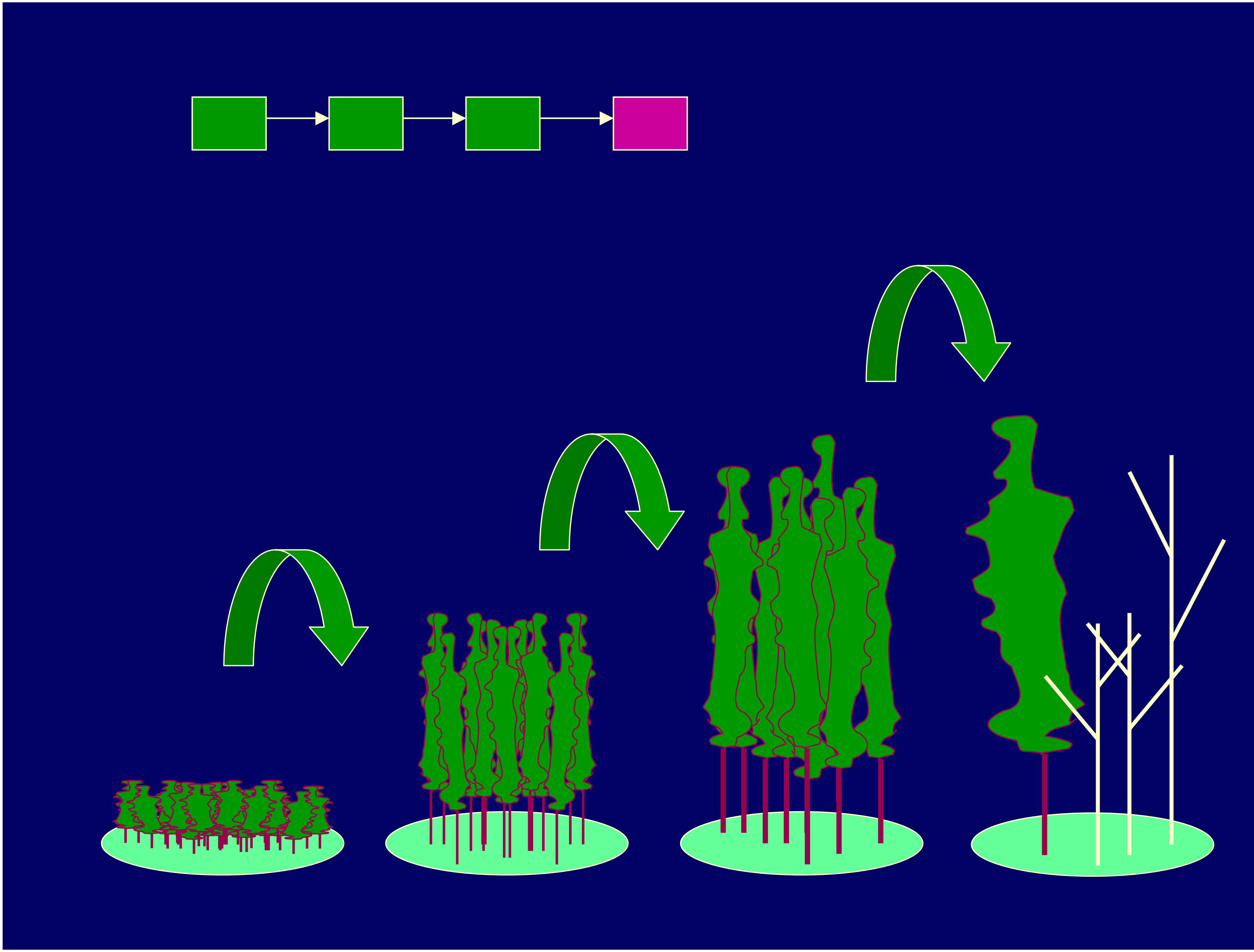
- To investigate forest composition under shifting disturbance regimes at times scales that are difficult to empirically investigate.

- **An initial model uses differential equations to simulate large areas of forest being transferred from one cover state to another.**

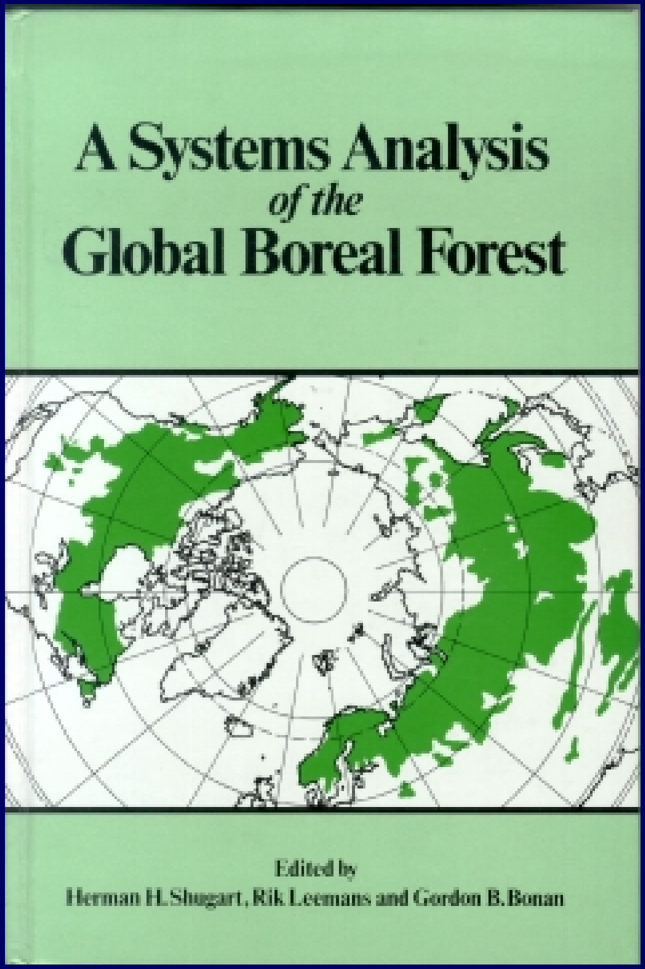
- **Rates of change and transfers among cover states are determined from species attributes or direct empirical measurements.**

The fundamental idea is that the successional development of a forest is a progression of changes. The model keeps track of the area in each forest cover type and describes this dynamic change as a differential equation





We used an already compiled synthesis of boreal sylvicultural data to estimate the rates of expected landscape change.



Using silvicultural descriptors to estimate change

Table 2.15. *Silvical parameters of boreal tree species in Eurasia*

Values for *ETSmax*, *ETSmin* and *Tcold* are estimated by overlapping of species distribution maps and climatic maps prepared by Dr. W. Cramer (personal communication). Values for *Hmax* in brackets are obtained in estimating *IS* from height and diameter data (see parameter explanation). Values for *B2* and *B3* are estimated so that the parabolic function for the diameter–height relation matches the asymptotic one (see explanation for parameter *IS*). Values for *Tl*, *Tdr* and *Tn* are based on unpublished data by N. P. Polikarpov. Unknown values are indicated by dashes.

Species	*ETSmax*	*ETSmin*	*Tcold*	*SFrq*	*Disp*	*Sfire*	*Smsl*	*Sm*	*Sdr*	*Slmin*	*Rlr*	*SprTnd*	*SprMax*	*SprMin*
Abies sibirica	1450	510	−35	30	T	F	F	T	F	4	T	0	0	0
Betula pendula	2300	410	−40	90	T	T	F	F	T	—	F	—	—	—
Betula pubescens	2050	340	−40	90	T	T	T	F	F	—	F	—	—	—
Chosenia arbutifolia	1750	240	−45	90	T	T	T	F	F	—	F	—	—	—
Larix gmelinii	1500	250	−45	33	T	T	T	F	T	—	F	0	0	0
Larix sibirica	1500	300	−33	20	T	T	T	F	T	—	F	0	0	0
Larix sukaczewii	1750	390	−22	20	T	T	T	F	T	—	F	0	0	0
Picea abies	2250	470	−17	24	T	F	T	F	F	5	T	0	0	0
Picea ajanensis	1800	750	−38	40	T	F	F	T	T	—	T	0	0	0
Picea obovata	1500	320	−40	8	T	F	F	F	F	—	T	0	0	0
Pinus pumila	1600	240	−45	90	F	F	F	F	T	—	T	0	0	0
Pinus sibirica	1450	490	−35	65	F	F	F	F	F	6	F	0	0	0
Pinus sylvestris	2350	450	−40	24	T	T	T	F	T	—	F	0	0	0
Populus tremula	3000	400	−40	35	T	T	T	F	F	—	F	—	—	—

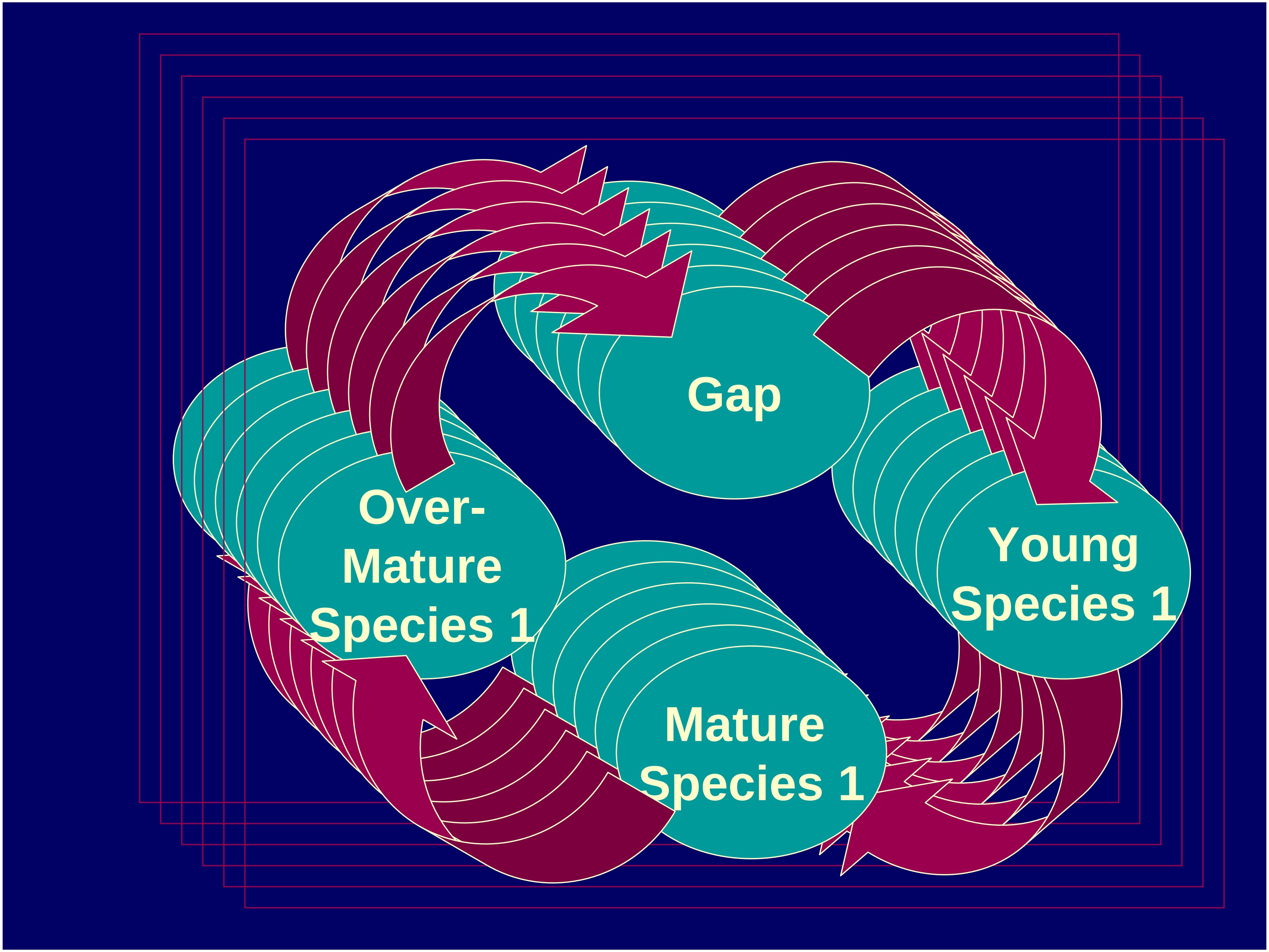
Longevity

Growth Rate

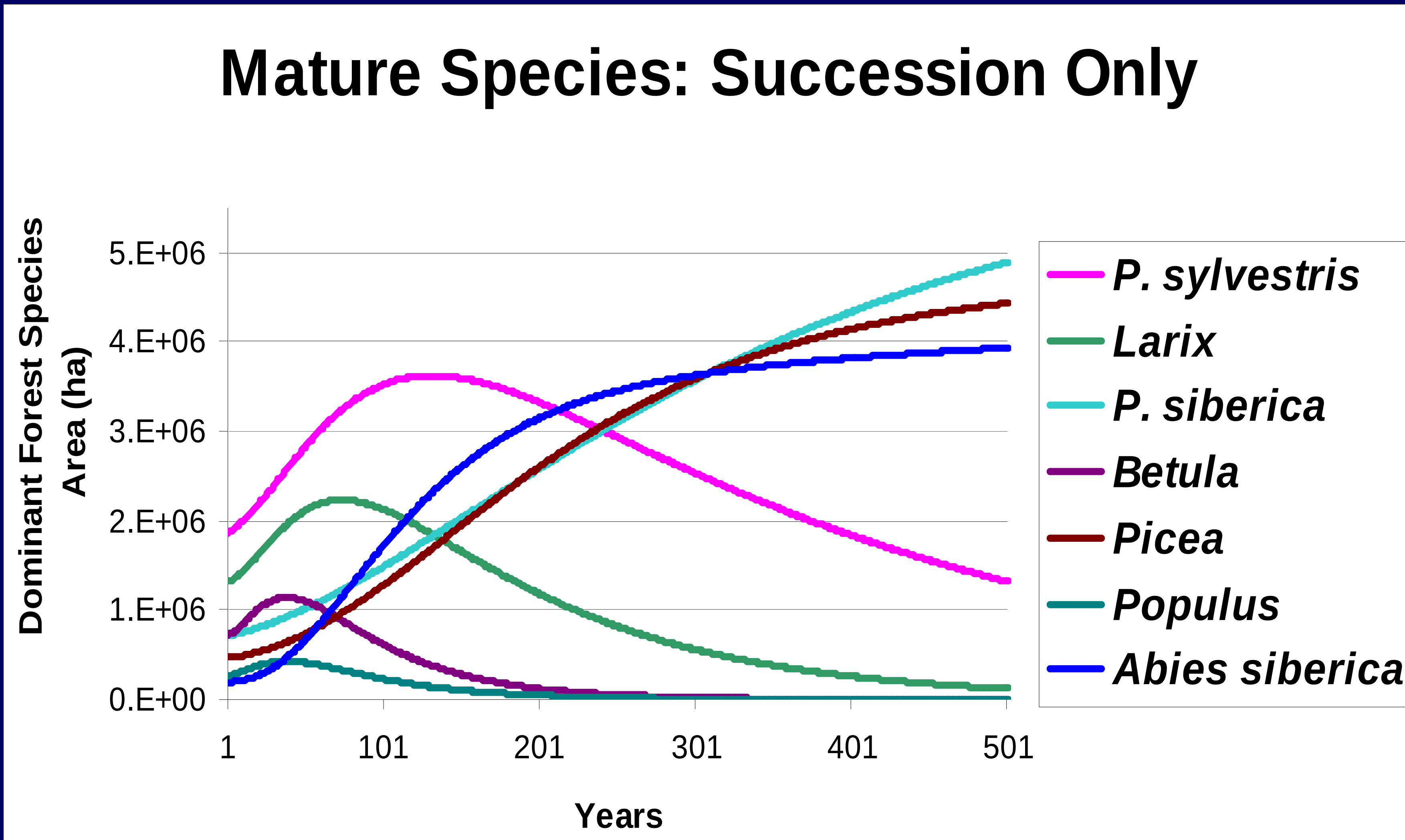
Tolerance to environmental factors

Table 2.15 (*cont.*)

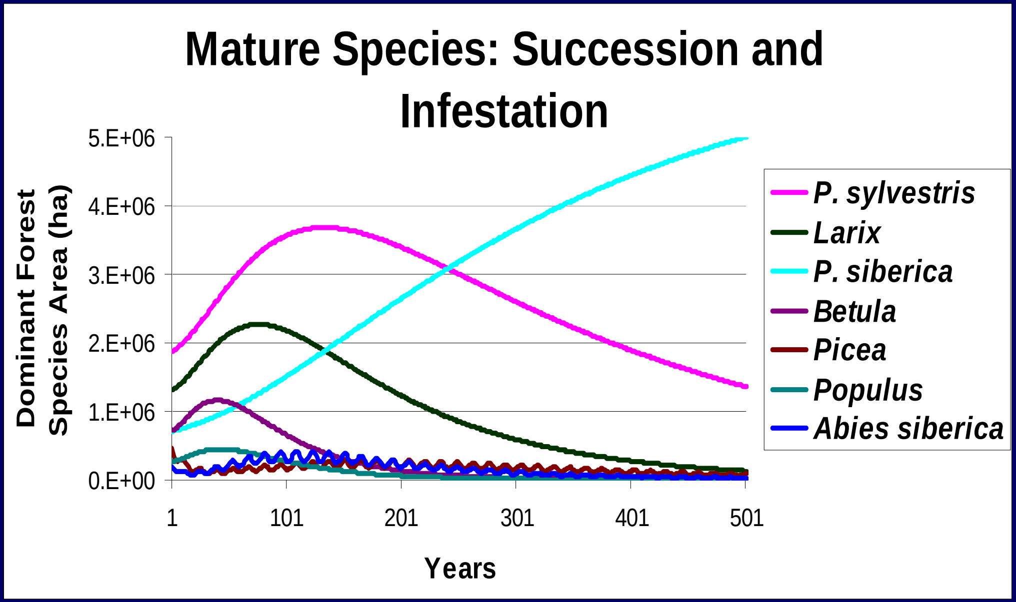
Species	*Hmax*	*Dmax*	*I[illegible]x*	*AGEmax*	*IS*	*B2*	*B3*	[illegible]	*Tl*	*Tdr*	*Tn*	*Tfr*	*Tfl*	*Bog*	*Ptol*
Abies sibirica	40 (42.4)	80	—	300	1.0329	91.18	0.5065	83.0	1	[illegible]	5	3	2	1	1
Betula pendula	30	60	100	[illegible]	1.0987	92.36	0.7448	235.0	[illegible]	1	1	1	1	1	2
Betula pubescens	30	60	—	100	1.0987	92.36	0.7448	235.0	4	5	1	2	2	2	2
Chosenia arbutifolia	37	80	—	130	—	89.06	0.5567	314.0	5	5	5	—	4	1	1
Larix gmelinii	40 (38.8)	140	120	400	1.0914	78.84	0.4022	164.0	5	2	2	1	3	2	3
Larix sibirica	45	180	—	450	1.4897	94.85	0.5155	165.0	5	1	2	1	3	2	2
Larix sukaczewii	40 (42.0)	120	—	350	1.4701	93.40	0.5368	161.0	5	3	2	1	2	2	1
Picea abies	63	170	70	570	1.0761	75.62	0.2320	152.0	2	5	3	3	2	2	1
Picea ajanensis	60	150	—	500	0.5649	57.20	0.1395	99.0	2	4	3	3	2	2	2
Picea obovata	40	50	—	500	1.0214	85.84	0.4769	97.0	2	5	3	3	3	2	2
Pinus pumila	7	—	4	200	0.5567	50.04	1.1121	13.5	3	4	1	3	3	2	3
Pinus sibirica	45	190	—	800	0.8955	69.81	0.2792	83.0	2	4	3	2	3	2	2
Pinus sylvestris	48	190	100	600	0.9772	81.81	0.3588	144.4	4	1	1	1	3	2	1
Populus tremula	42	100	150	150	1.3910	90.29	0.5016	225.0	4	2	3	3	3	1	1


Gap
Young Species 1
Mature Species 1
Over-Mature Species 1

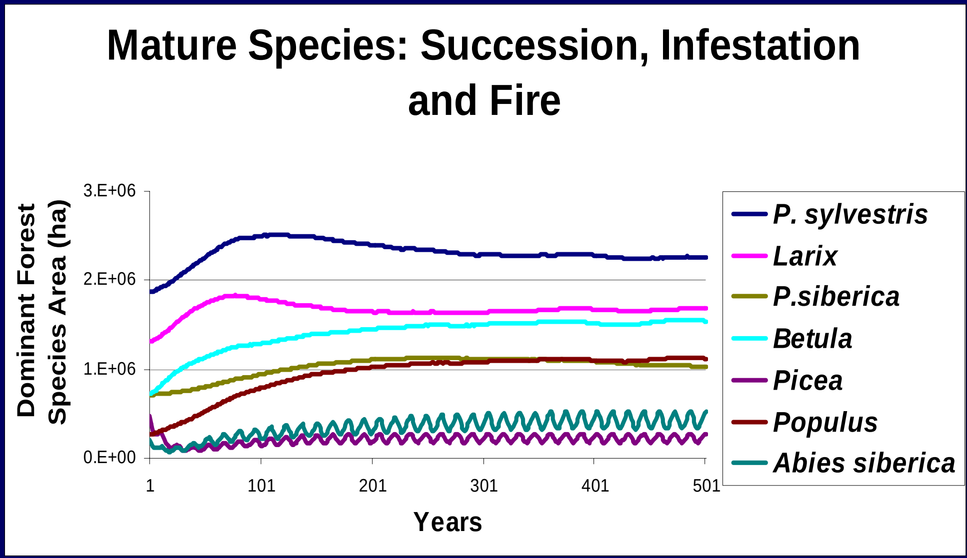
Results



Mature Species: Succession Only
Dominant Forest Species Area (ha)
5.E+06
4.E+06
3.E+06
2.E+06
1.E+06
0.E+00
1
101
201
301
401
501
Years
P. sylvestris
Larix
P. siberica
Betula
Picea
Populus
Abies siberica



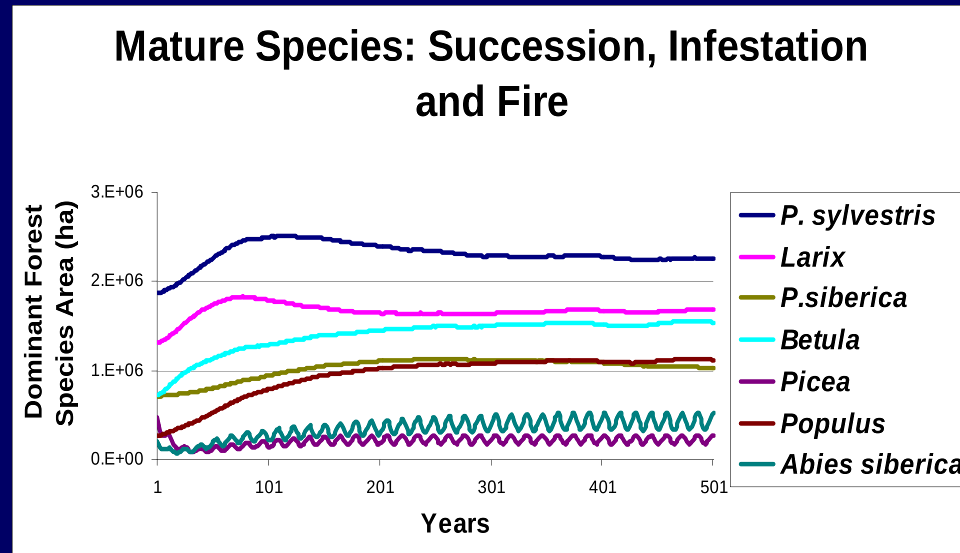
Infestation

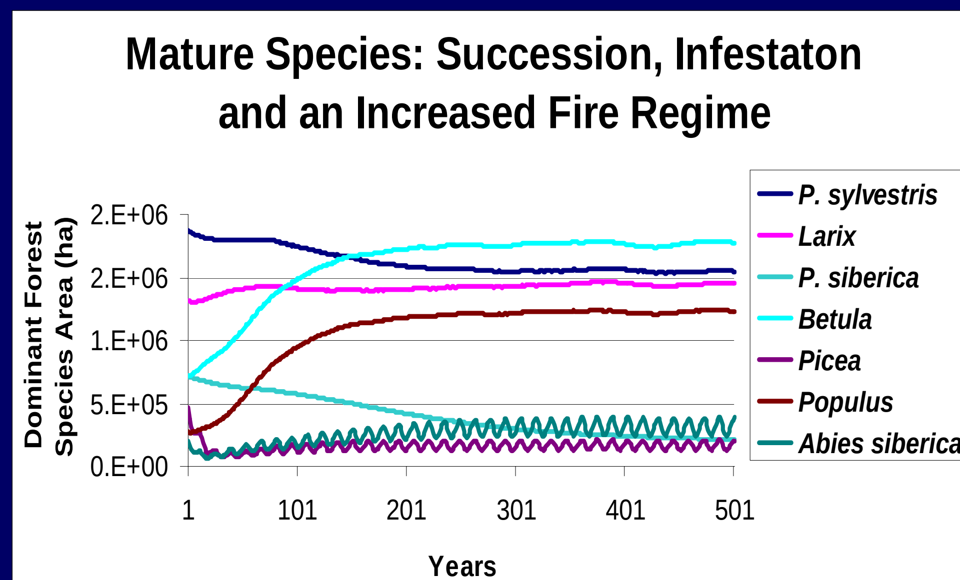


Mature Species: Succession, Infestation and Fire
Dominant Forest Species Area (ha)
3.E+06
2.E+06
1.E+06
0.E+00
1
101
201
301
401
501
Years
P. sylvestris
Larix
P.siberica
Betula
Picea
Populus
Abies siberica

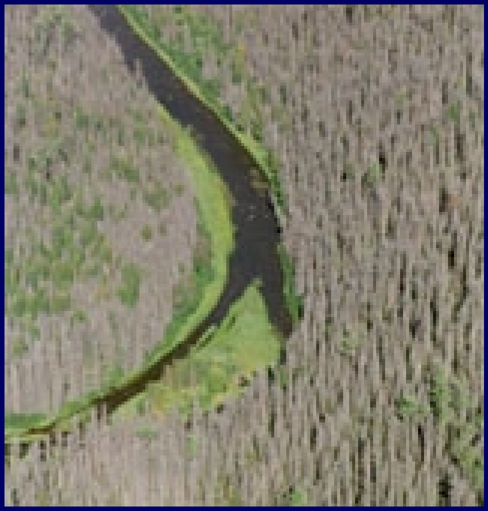
Fire

Fire

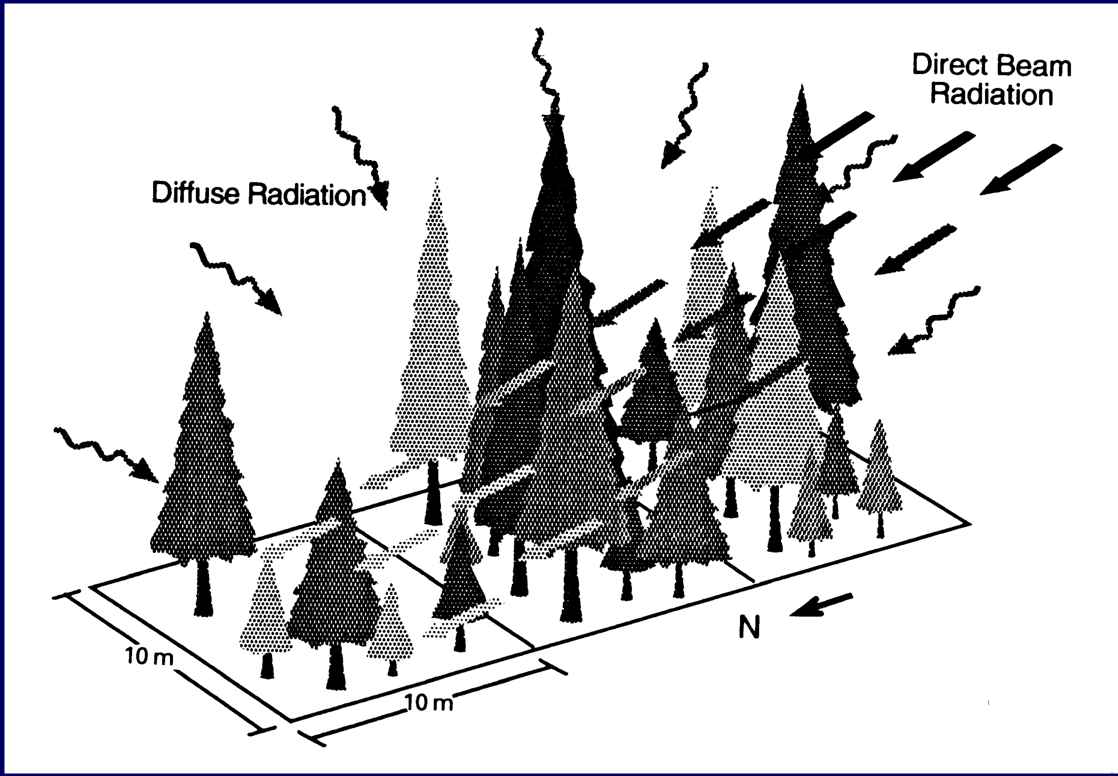

Mature Species: Succession, Infestation and Fire
3.E+06
2.E+06
1.E+06
0.E+00
1
101
201
301
401
501
Years
Dominant Forest Species Area (ha)
P. sylvestris
Larix
P.siberica
Betula
Picea
Populus
Abies siberica


Mature Species: Succession, Infestaton and an Increased Fire Regime
2.E+06
2.E+06
1.E+06
5.E+05
0.E+00
1
101
201
301
401
501
Years
Dominant Forest Species Area (ha)
P. sylvestris
Larix
P. siberica
Betula
Picea
Populus
Abies siberica

Current work involves the development of an individual-based model of forest dynamics that integrates directly with the landscape simulator.



Individual-based Model



The 6-week visit of Slava Kharuk allowed us to reparameterize the land-cover change model. We have also developed an spatial individual based model for the central Siberian site.